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Guidelines for Best Practice and Quality Checking of Ortho Imagery

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1 Introduction

1.1 This document

This document contains guidelines for quality checking of orthorectified imagery, and the expected best practice approaches required to achieve good results. The guidelines here apply to digital orthoimagery products, generated from either film cameras or digital instruments, on both airborne or satellite platforms for the scope of applications covered relates to the management, monitoring and control of agricultural subsidies (usually 0.5m-10m pixel size) and to some degree (particularly very high spatial resolutions) large scale mapping or cadastre applications (0.5m or better). All stages of the production chain affecting geometric accuracy and radiometric quality of the final product are considered.

1.2 Justification and applicability

The EC has always adopted an accuracy specification for geometric correction of images, but the basis of this specification is product-based and formal methods for testing conformity with the specification have not been defined in the usual technical specification documents or the ITTs associated with the projects. It is therefore the purpose of this document to set out stable, definitive and robust methods for effective quality assurance of image geometry.

1.3 Nature and scope of these guidelines

The nature of these guidelines is to be descriptive, that is: to state what is to be done, without explaining in detail why. These guidelines aim to also avoid assumptions that specific software or equipment will be used. However, in order to assure quality it has been assumed that the equipment/software used does possess certain features or functions.

The scope of these guidelines is defined both by the processes to be considered – mainly radiometric processing and ortho rectification – and by the type of digital image data to be processed. However the partial differences the general photogrammetric workflow applies analogously to all systems and therefore only important deviations are pointed out in the guidelines.

1.4 Document history

This original version of this document provided as a contract deliverable executed by Remote Sensing Applications Consultants Ltd. and the Geomatics Department of University College London, in 1998. The contract was funded by DG IV (AGRI) and supervised by the MARS project of the JRC.

The draft specifications were revised, expanded, and in some cases reformulated by the MARS project, resulting in the version 1.5 that was made available in 1999.

Version 2 (2003) built further on the earlier document, updating in particular the sections on scanning, digital airborne data, and Very High Resolution satellite image ortho-rectification best-practice. The revision was done in consultation with image suppliers, system manufacturers, and orthoimage producers.

The current version (v3) consolidated the information that was introduced to the document in the last five years while following a more process-based structure. The main update concerned with image resolution, radiometry, processing and mosaicking. The expert panel that participated at the meeting in ISPRA greatly contributed with their comments on the previous version and with their ideas for this revision.

2 Requirements of Quality Assurance

2.1 Quality Assurance

Quality assurance (QA) is a set of approaches which is consciously applied and, when taken together, tends to lead to a satisfactory outcome for a particular process. A QA system based on these guidelines will employ documented procedural rules, templates and closely managed processes into which various checks are built. Quality controls (QC) and quality audits are important checks within a QA system.

2.2 Quality Control

A quality control (or check) is a clearly specified task that scrutinises all, or a sample, of the items issuing better during, or even at the end of, the ortho-rectification process in order to ensure that the final product is of satisfactory quality. The scrutiny involves review, inspection or quantitative measurement, against well defined pass/fail criteria which are set out in these guidelines.

2.3 Quality Audits

A quality audit is a qualitative quality control that covers an area of activity as a whole. The EC will normally appoint an independent quality auditor to inspect the ortho-rectification work in progress at the contractor's site. Quality audits will be carried out by comparison of actual practice with the applicable quality assurance procedures contained in these guidelines.

"Normal" audit checks which are carried out 'Once' will be repeated again if a corrective measure is requested. "Tightened" audit checks will follow an audit trail for suspect products or regions and will be introduced if

- earlier audits result in doubts about performance
- results from QC do not meet the specifications given in previous sections
- results from external QC do not meet the tolerances in the ITT.

2.4 Quality Control Records

The information used in a Quality Audit will mainly be provided by quality control records (QCRs) which are generated during the work, by the people doing the work. QCRs take a variety of formats, such as paper forms completed manually, printouts or computer files recording the result of a particular procedure, or just simply hand-written records in log books.

The key features of any QCR are that it

- is marked with a date
- uniquely identifies the item, operation or product to which it relates
- identifies the operator who generated the QCR
- may be countersigned by a supervisor or other independent inspector (only for the most important records)
- is stored in a well defined and predictable location so that it can be found easily by others.
- These guidelines identify the essential (minimum) set of QCRs required for QA of ortho-rectification.

2.5 QA Phases

Procurement of ortho-rectified images almost always occurs through a process of competitive tendering. The technical execution of the work is therefore not directly under the control of the EC so the QA process takes this into account. There is a sequence of three activities which can be controlled by the EC and which affects the quality of the outcome:

- ITT specification and tender evaluation

  - *These guidelines distinguish between work components that are explicit requests in an ITT and those that are looked for in the response.*
- Quality Control during the geometric correction work, including input data
  - *The purpose of QC during the work is to identify potential problems early. Potential problems are defined as those that could cause the geometric error in a product to exceed the specified tolerance.*
  - *Internal quality assurance will be the responsibility of the contractor and will result in the production of QCRs.*
  - *An auditor independent of the contractor will carry out external quality audits (physical checks of conformity to specifications and scrutiny of QCRs produced by the internal QA) and a limited amount of sample-based QC.*
- Measurement of geometric error in the output images
  - *An independent external quality control will be carried out on a sample of geometrically corrected image products in order to establish an overall accuracy. The acceptance criterion for this check is the tolerance stated in the ITT.*

3 Image resolution

Defining the different types of image resolution (spatial, spectral, radiometric and temporal) is not in the scope of this document (Poon et al, 2006). It is however important to make sure that the choices being made when planning a project will be consistent and cost effective.

3.1 GSD

Since the introduction of digital technology the scale does not provide by itself a clear measure for the **spatial resolution** of the imagery as the size of the CCD element (respectively the scanning resolution for film imagery) has been introduced to the equation. The use of the Ground Sampling Distance (GSD) which represents the ground distance covered in a pixel has been established as the most common measure of the spatial resolution of an image (although not a sufficient condition).

[GSD = (H/f)*CCD]

When orthoimage is to be produced it is the output pixel size that defines the GSD of the imagery. In case of digital sensors the ratio of the final ortho resolution to the GSD is 1:1 whereas for film cameras should be at least 1.2:1 (see 6.2.1).

GSD size has great impact to the project cost for both analogue and digital airborne imagery; generally halving the GSD size will increase the cost of a project 2-4 times.

3.2 Radiometric resolution

The radiometric resolution of the acquired images should be at least 8bits/pixel but 11-12 bits is highly recommended. The market seems to move towards even higher resolutions with most digital airborne cameras operating already in 14-16 bits.

3.3 Spectral resolution

The spectral resolution of the imagery can be panchromatic, colour, NIR or IR. It is an important decision to make which can restrict the options of sensors or/and platforms for image acquisition and therefore the final choice should be justified by the scope of the application.

3.4 Temporal resolution

This also a very important parameter to consider as it affects the cost and the time plan of the projects. The main questions to address concern with:

- The use (or not) of archive imagery if available
- Defining the window for the acquisition which can vary depending on the project's scope (e.g. leaf-on imagery)
- Defining the update cycle of the imagery

4 Sensor calibration

4.1 Sensors

Camera calibration is a very important requirement at the photogrammetric process. The introduction of the digital airborne sensors has created a large variation of systems incorporating different imaging geometry (frame-line, single-multi heads) and can integrate auxiliary sensors (GPS/INS).

Whereas digital airborne cameras are expected to operate under a similar workflow practice; and such systems are subject to the same QA requirements as standard film cameras, their internal geometry can be very different than this of a film camera.

4.2 Calibration of film cameras

For the analogue airborne cameras the calibration is a very well-established process taking place in specialised laboratories which provide a camera calibration certificate normally valid for 2 years. Such certificates provide all the necessary information of the camera interior geometry (principal distance, distortions etc) in a standard format and therefore it is not necessary to be described here in detail.

4.3 Calibration of digital airborne cameras

Due to the degree of complexity of the digital systems compared with the traditional analogue cameras the classic well established laboratory calibration process is changing and new calibration approaches are investigated. In so far the vendors provide camera calibration certificates based on their system-driven calibration processes either laboratory or in-situ.

Appropriate geometric calibration, for example factory calibration or field calibration of the instrument using an official test field (or validated by the instrument manufacturer), should be current (usually within past year).

Radiometric calibration would normally be expected to be dependent upon factory certification and state at least:

- The level of live cells for each CCD array.
- The radiometric resolution performance (at least 12-bit)
- Metrics for the range of each spectral band (R,G,B, etc)

Although such calibration methods should provide sufficient accuracy for most of the mapping applications, the need for the establishment of generally accepted procedures for the certification of digital airborne cameras has been well-identified in the last years:

- In Europe EuroSDR initiative on European Digital Airborne Camera Certification (EuroDAC[2]) has began since 2003 and for the coming years it is planned to test the geometric and radiometric aspects of the digital sensors in order to conclude on the strategy to be followed (Cramer, 2007).
- In USA, USGS has decided to shift from individual sensor certification to the quality assurance of the whole digital sensor's product line. Following this strategy USGS has already begun certifying commercial airborne digital cameras (Stensaas et al, 2007).

5 Airborne image acquisition

5.1 Scope

The recent advances of the digital airborne cameras provide different options for getting to the desired product but they can also create difficulty for making the right choices. The scope of this chapter is to outline the main issues to be addressed for data acquisition planning and execution.

5.2 Flight plan and execution

The flight planning for airborne image acquisition should ensure that issues related to height above ground, overlaps, sun angle etc. issues are adequately addressed.

5.2.1 Flying height

The flying height is derived using the equation of 3.1 and it should be defined so that the images will be acquired at the predefined GSD.

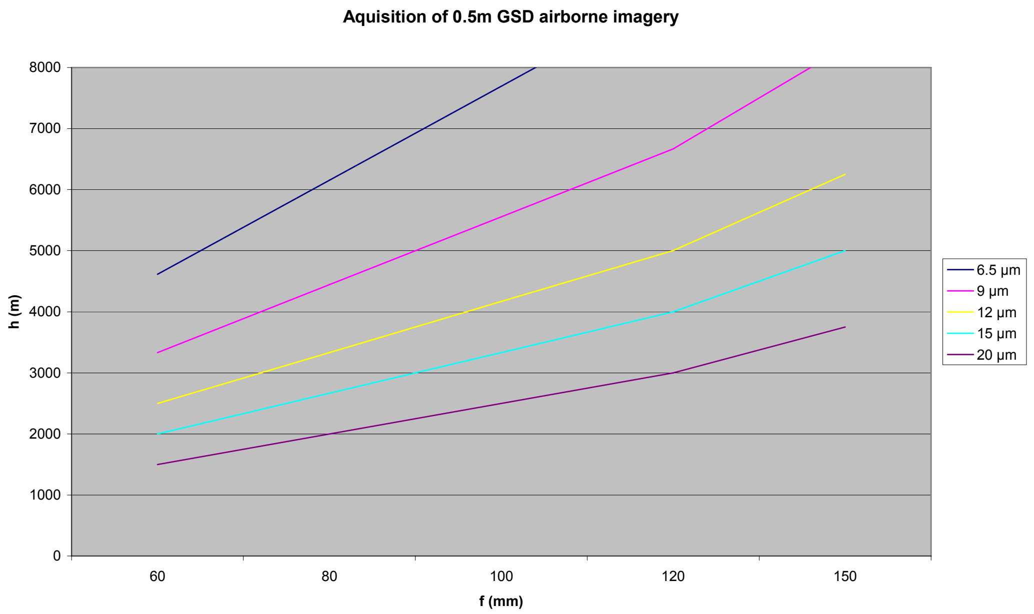

Figure 1. Flying height for different camera configuration (f, CCD size).

5.2.2 Image overlaps

Forward overlap should be at least 60% when stereo imagery is collected whereas for mosaicking 20-30% could be used but with the compromise of using off-nadir part of the images during the orthorectification (not recommended).

Side overlap must ensure that all the surveyed area will be covered with imagery and generally it will be in between 15 – 45% depending on the terrain relief. When fully automatic triangulation is foreseen the overlap should be up to 60%.

5.2.3 Scale variation

Scale variation is caused mostly due to variation of relief and will result in varying GSD. Usually should not exceed 10%-15% (depending on flying height) but in mountainous areas could be difficult to achieve.

5.2.4 Roll and drift

In average roll should not exceed +/- 1 degree across the flight with a maximum of 3 degrees for a single image. The displacement due to drift should not be more than 10% of the image width for any successive 3 images.

5.2.5 Flying conditions

Flying conditions will usually ensure that solar angles relative to the flight direction and time are acceptable to avoid excessive glare/shadowing, and that individual photos have tolerable cloud cover and sufficient contrast in the features of interest.

In particular sun angle should not be lower than 30 degrees (optimal 40-60) in order to avoid long shadows in the imagery. Collecting imagery at North to South directions would also minimise the overall effect of shadows in a flight.

5.2.6 Auxiliary orientation equipment (GPS INS/IMU)

The integration of additional sensors with the digital airborne cameras is used for the direct determination of the trajectory mandatorily for line sensors or auxiliary for frame cameras. At any case flight planning should address the following:

- DGPS processing. Due to the important reliance upon DGPS processing the proximity to GPS base station(s) should ensure adequate solution. Under normal conditions this distance would be <80km but technology changes rapidly.
- GPS Interval/frequency every 1 to 10 second (commonly 1sec)

5.2.7 Sensor configuration and settings

Cameras settings can vary depending on the atmospheric and lightning conditions. Particular care should be taken for deciding upon:

- Exposure control. The camera should be set according to the lightning conditions in order to avoid under/over exposure, smear or sensor blooming.
- Use of filters. The use of the appropriate filters can reduce the effects of haze, vignetting or lens falloff due to the atmospheric conditions. Usually such filters are provided together with the specific sensors or films by the manufactures.

For pushbroom sensors (line geometry) the configuration should be such that:

- Angle of CCD bands used for orthoimage product as close as possible to nadir
- All bands (RGB,CIR or even PAN if pansharpening required) composite at same angle

5.3 Input data

The quality of materials and equipment used to create the input data is critical to a satisfactory result. Any digital processing must carry out an input data quality assessment (IDQA) which will check that the images were captured correctly (Table 1).

Item	Best practice	Internal QCR/QA
Film	High resolution panchromatic or colour aerial film	Physical verification of film, manufacturer's technical documentation.
Camera	High quality, modern aerial camera preferably with FMC (TDI if digital) and computer managed exposure mechanism.	Physical inspection. Date-stamped camera calibration certificate
Flight Navigation	Camera linked to on-board INS. GPS controlled photo logging.	Inspection of flight log data. Check that air camera positions usable in GPS-block adjustment.
Overlap Completeness	Forward overlap at least 60%, Lateral typically 15 - 25% but should be increased if mountainous areas (45%) Contractor could specify lateral overlap up to 60% for fully automatic aerotriangulation. 100% coverage with specified overlap	Analyse log of photo centres and flying height for conformance with completeness and overlap Or if no flight data: Photo-laydown
Scale Variation	GSD variation should not exceed 10-15% depending on the terrain relief and the flight height	Use GCP positions and DEM to generate scale for each photogramme

Table 1 : Best practice for Input data quality assurance

Input files should be self-documenting (e.g. flight, photo number), with additional metadata in tables linked to the file name. The following information should be recorded:

- For each flight: Camera identifier and Calibration certificate, Type of film, Identifiers for film rolls used, start/finish time, Weather Conditions (as recorded at airport Meteorological station: should include temperature, pressure, wind speed/direction at one standard time during day).
- For each photo: Flight identifier, Film roll and Exposure number, Flying height, Ground coordinates of Exposure station (from INS/GPS), Time of exposure, Date of Scanning.

6 Radiometric processing

6.1 Scope

This section covers the expected requirements and best practice approach to be applied concerning image processing for both film and digital acquired images.

6.2 Film Scanning

When imagery is acquired with a film camera, the original film (or, alternatively, the diapositives) will be scanned with a photogrammetric quality scanner of the following general characteristics:

- Geometric precision of scanner < 5µm
- Nominal scan resolution of 12µm to 25µm which are typically used for topographic mapping applications.
- Final radiometric resolution of at least 8-bit per channel. However, it is strongly advised that 11 or 12-bit scanning systems are used.

6.2.1 Scanning resolution

The pixel size of the scanned images is related to the image scale and the final resolution of the orthoimage. It is recommended that the resolution of the scanned image should be 1.5 better that of the orthoimage (at least 1.2).

Photo scale	Scanning Resolution (µm)	GSD of scanned image (m)	Final ortho resolution (m)
1:40.000	15	0.6	1.0
1:35.000	17		
1:30.000	20		

Table 2. Indicative scanning resolutions for different photo scales.

6.2.2 Image scanning QA

The scanning process will be checked frequently by the contractor who should perform and submit a quality assurance report at delivery of data; the quality control data ("scan file") produced by the scanning software would normally be a suitable information source to include. The quality assurance report should also contain information on:

- frequency, execution, and details on geometric quality control of the scanner using e.g. a calibrated photogrammetric grid performed before and at the end of the project.
- frequency, execution, and details on radiometric quality control using e.g. a photographic step tablet performed before and at the end of the project
- photogrammetric interior orientation. An affine transformation of the images will be expected to produce an RMSE of <0.5p (four corner fiducials), with no residual greater than 0.7p. In the case of use of eight fiducial marks, the RMSE can increase to <1.0p (although again, no residual should exceed 0.7p).
- details on radiometric quality tests of the scanned photographs as described in 6.3.

Item	Best practice	Internal QCR/QA
Scanning Equipment and Materials	Use precision photogrammetric scanner Negatives should be scanned (positive output) if possible.	Physical inspection Interior orientation will be tested for all scanned images automatically or manually. Reject those with RMSE beyond tolerance (>0.5p for 4 fiducials).
Scanned Pixel Size	Pixels size should be 1.2-1.5 better than the pixel of the orthoimage. Typical practice: 12µm- 25µm	Printout of metadata for digital files (listing and file size in bytes)
Scanner Accuracy	Scan geometry RMSE < 5µm No residual > 15µm	Repeated test scans using a photogrammetric grid, measure at least 5 x 5 points. Compute x, y residuals and RMSE (x and y) after an affine transformation. First test before start of photo-scanning then repeated regularly at intervals depending upon stability of system. Plot residuals for row and column on a control chart.

Table 3. Geometric QA for image scanning

6.3 Image radiometric quality assurance

This section concerns with the radiometric quality of the images either scanned or digitally acquired. It is recommended that the controls are implemented in automated processes that permit the generation of QCRs for each file produced, it should be noticed though that this is not always easily quantified due to the nature of some effects or due to the lack of commercially available tools.

The radiometric QA should include the following checks:

- Examine image histograms to ensure that the available dynamic range was fully used but without saturation. If a DRA is applied to the original image, a 5% margin (in terms of DN) on the bright side and 5-10% on the dark side should be left for further processing. Histogram optimization is recommended to be made on a collect basis (same conditions during acquisition) and not for individual images.
- Saturation should not exceed 0.5% at each tail of the histogram (e.g. the resulting 0 and 255 values for an 8-bit image), for the full image. For colour/multispectral images, this assessment should be made in the Luminosity histogram and/ or each channel.
- Contrast: The coefficient of variation[1] of the image DN values should be in the range of 10-20%. Exceptions will, however, occur where the image contains large snowed areas, features like sun-glint on water bodies, etc.
- Cloud cover: The usual tolerance for maximum cloud cover is defined as 5-10% for individual images or/and in average depending on the project's purposes
- Noise: The image quality can be significantly reduced by the existence of high noise rates. Visual checks, especially in homogeneous areas, can be made by applying strong contrast enhancement in an image. The standard deviation of the image DN values is used to quantify the existence of noise in an image. It can be applied at the whole image as a global statistic (standard deviation should normally be less than 12 at all bands) and/or a further analysis can be made in selected homogeneous/inhomogeneous areas.
- Clear visibility of fiducial marks (if existing)
- Colour mis-registration can be caused when a digital sensor collect different channels at shifted times. It can be detected visually in an image along edges and it should not exceed 1 pixel.

[1] Represented as the Standard Deviation of the DN values as a percentage of the available grey levels

- Existence of scratches, dust, threads, hot spots, haze, shadows, colour seams, spilling, artefacts etc. These checks are usually visual and qualitative since such effects are not easily modelled and/or quantified.

6.4 Input data

Sufficient checks should be carried out to ensure that the following parameters are respected:

- a file should be provided giving the meta-data characteristics of the files delivered (file name, photo number, CD number, radiometric statistics including the mean and standard deviation of histograms, results of sample tests, date and time of scanning, operator, etc).
- Correct labelling of files; this should follow a standard Windows platform naming convention, without spaces and with a name plus extension (file type) e.g. *photo_nr.tif*. The naming used should correspond with that used in the meta-data table described above.

All the images will be delivered in a widely used, well-established format e.g. TIFF 6. Image compression issues are discussed in 6.5 whereas tiling should be generally avoided. It is recommended that an image in the proposed format be supplied ahead of the delivery to confirm acceptance of the format used.

Meta data concerning the image (date, source, photo number etc.) could be included as a tag in the image header.

6.5 Image Compression

Compression is used in order to reduce the large data volume of high resolution images. Manipulating such large data volumes can be challenging during all stages of the photogrammetric process e.g. image download/ upload, processing and storage. The loss or not of data defines the classification of compression methods

Lossless is a compression algorithm that allows the image to be reconstructed exactly as the original. Because of the obvious advantage of quality maintenance such methods are used without any consideration but they provide low compression rates, generally about 2:1 (original data volume /compressed data volume). TIF and LZW-TIF are commonly used as lossless compression schemes.

Lossy compression techniques involve some loss of information and as a result, the original image cannot be exactly reconstructed. In return for accepting varying levels of distortions and artefacts in the reconstruction, higher compression ratios are possible. JPEG is the most common form of lossy compression. The use of lossy compression is not recommended for images to be used for orthoimage production but it can be used for automatic DTM extraction (matching) with little compromise to the final accuracy (Robinson et al., 1995).

The visually lossless compression (misnomer term) is actually a lossy compression at low rates. It means that the compressed file is "visually indistinguishable from the original", however there is still information loss involved in the compression which can be significant, for example in case that automated techniques for feature extraction are applied on the orthoimage. Visually lossless compression is subjective and therefore should be used with care and normally as the last stage of image processing for delivery and storage purposes. JPEG2000, ECW and MrSID are typical visually lossless codecs (wavelet based).

7 Ground reference data

7.1 Accuracy requirements

GCPs should be at least 3 times (5 times recommended) more precise than the target specification for the ortho, e.g. in the case of a target 2.5m RMSE, the GCPs should have a specification of 0.8m RMSE or better.

GCPs should ideally be determined from field survey, using DGPS supported with geodetic control points or a GPS reference station network, though direct measurement survey methods for precise ground control are also acceptable. However in exceptional cases if this is not possible they may be scaled from maps of sufficiently high precision, or taken from an oriented flight of an appropriate scale measuring in stereoscopic mode or from orthoimages and associated DSMs/DTMs.

Where ground control is obtained from topographic mapping, a digitization error (0.02mm at the map scale) must be allowed for, thus an accuracy improvement factor of at least *five* is recommended when estimating a suitable map scale for planimetric ground control points[2].

7.2 Selection of GCPs and CPs

With air-photos the recommended source of ground reference is ground surveyed control of *well defined points* (FGDC, 1998*)*. It is important that the selected points are:

- well-defined on the images and that they could be measured accurately (manually and semi-automatically). After selecting the points in the images then they will be measured in the field.
- easily identified and accessible on the ground (not in private properties, on buildings etc)
- well-defined on the independent source (e.g. map) should the point not be surveyed directly

The selected points will differ depending on the type of dataset and output scale of the dataset. For orthoimagery with a 1m pixel size, suitable well-defined points may represent features such as small isolated shrubs or bushes, road intersections (corners) in addition to right-angle intersections of linear features and circular objects. For lower resolution images, the same principles should apply, although the features to be detected may be more often similar to cartographic representations. Care will be taken not to choose features which are over-generalised on maps.

Buildings which represent vertical displacement (corners of buildings, telegraph poles) should not be selected as checkpoints (unless if DSM is used).

The same quality requirements apply for the check points used by the contractor for internal QC (see 12.5).

7.3 Documentation associated with ground reference data

Ground reference data (GCPs and check points) must be well documented, in order to provide traceability. In essence, this documentation is a vital QCR to be created by the contractor. A list should be maintained showing:

- point identifier (unique to project)
- X, Y, Z coordinate
- Image coordinates in at least 2 images
- Source (GPS; photogrammetric mapping service archive, geodetic survey, topographic map, etc.)
- Expected (or proven) planimetric quality of the point in meters (RMSEx, RMSEy)

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[2] for example if output specification is 2.5m 1-D RMSE (equivalent to 1:10,000 scale), then control data derived from mapping must be 0.5m 1-D RMSE, i.e. not derived from maps smaller than 1:2,000 scale. For vertical control, precision should be to at least 1m and accuracy better than 2m RMSE.

- Expected (or proven) vertical quality of the point in meters (RMSEz)
- Sketches and/or image extracts of sufficient zoom
- Pictures of the location of the GCPs taken on site
- Plot of block with nadir points, image outlines and position of GCPs
- Other remarks

In addition, supporting information included with the ground reference coordinates must state all parameters for the coordinate system, including the ellipsoid and identification of all geodetic controls used during the field survey.

Each point should be marked on an image or map and labelled with the point identifier used in the list. Marking should ideally be done in the field at the time of survey, *preferably* on the digital images. The entire dataset should be archived with the image extracts (image file) clearly marked with precise GCP locations and identifiers. An ideal approach for storing and manipulating these data is in an environment linked to the final orthoimage dataset.

8 Airborne image orthorectification QA

8.1 Scope

This section outlines the process of creating orthophotos from airborne imagery, from the perspective of assuring final product quality. The guidelines detailed here are generally valid for medium scale (1:20 000 to 1:40 000) scale source air photos and the geometric tolerances are based on the ASPRS map accuracy standard (ASPRS 1989, FGDC 1998) and it is known to be achievable if the data capture and processing specification given in these guidelines is followed.

Geometric correction tolerance is defined using one parameter: the maximum permissible RMSE of the check points. Tolerances are as stated in the relevant ITT.

8.2 Geo-reference

Geo-referencing concerns with the determination of the exterior orientation elements of the sensors for the time of image acquisition. The number and pattern of GCPs recommended for possible flight configurations are listed into the table below:

Purpose/Method	Number of GCPs
Orientation of a single model	Minimum four (allows for testing of residuals)
Block adjustment for aerial triangulation, without airborne DGPS	One GCP every five base lengths (minimum) on the perimeter of the block and one GCP across all flight strips, every four base lengths.
DGPS controlled flight with cross strips (CBA-Method: Combined Block Adjustment)	One double GCP in each corner of a block and one double in the middle. Possible additional requirement of cross strips and more control within irregular blocks. Ambiguities which are not solved are removed as systematic errors in the Block Adjustment at great distances possible
DGPS controlled flight (no cross strips) (OTF-Method: Ambiguity resolution "on the fly".)	One double GCP in each corner of a block and one double in the middle. GPS Reference stations should be at a range of 50-100 km from survey area, depending on possible interference.
DGPS/INS controlled flight	One double GCP in each corner of a block and one double in the middle.

Table 4. Flight configurations and recommended GCPs patterns

8.3 Orthorectification process

Table 5 provides tolerances for each stage of the air photo orthorectification process. The measurements corresponding to each tolerance can be used to provide quantitative input to QCRs

Stage	Practical procedure	Recommended Acceptable tolerance
Tie points for aerial triangulation	Can be done manually but should be done automatically* if supported in software.	Automatic AT: Minimum of 12 per model, with good (Von Grüber) distribution Manual selection: Minimum of 6 per model
Interior orientation	Affine transformation of fiducials. Better to use eight fiducials, otherwise all four corner fiducials if not available.	See tolerances at 6.2.2
Absolute orientation	Measure model co-ordinates and transform to the ground	RMSE on GCPs from Block Adjustment <0.5x product RMSE specification
Relative Block Accuracy	Block Adjustment from tie points and GCP (and GPS/INS data if available at image level	RMSE ≤ 0.5 x input pixel size
Absolute Block Accuracy	Block Adjustment from tie points and GCP (and GPS/INS data if available) to ground level.	RMSE ≤ 1/3 specification Sigma0<=0.5 pixel
DEM grid spacing	Specify according to output scale and terrain relief For medium scale flights, break lines not required.	5 to 20 times of the orthophoto pixel size depending on the terrain flatness.
DEM height accuracy	Automatic DEM generation using stereo-matching and surface generation methods is recommended. Visualisation and cleaning of the output is normally required. [DEM can also be derived by Airborne Laser Scanning (ALS) and Interferometric Synthetic Aperture Radar (InSAR)]	2 x planimetric 1-D RMSE required
Resampling method	Cubic convolution or bilinear interpolation	Use of the most rigorous orthorectification model (selecting most nadir pixels)

Table 5. Tolerances for ortho processing of airborne imagery.

8.4 QCRs and quality audits for air-photo orthocorrection

Contractors should generate the following QCRs for their internal QA. They should be made available for inspection during a quality audit by an EC representative. The type of quality audit is shown in Table 6 as “Normal” or “Tightened” (see 2.3).

	QCR	Contractor Production Level	EC Inspection level (Sample)	Normal EC Audit Stage
1	Camera calibration certificate	100%	Normal (100%)	Before flight
2	Flight data including log of photo centres and flying height	100%	Normal (100%)	2 weeks before scanning (or 10 days after flight)
3	Control chart for the scanner performance (geometric)	Every 7 days, then 14 days if stable	Normal (once)	From start of scanning onwards
4	CV/Training certificate for DPWS operators	-	Normal (100%)	Start of AT
5	Table of ground reference data for GCPs and check points (used for internal QC)	100%	Normal (100%)	End of AT IO after scanning
6	Interior and exterior orientation results	100%	Normal (first few) Tightened (trail)	End of AT
7	Number of items rejected/reprocessed at each stage of internal QC	Complete list	Normal (monthly)	N/A
8	Visualisation of the DEMs: digital stereo image with DEM data overlain, shaded relief, contours	100%	Normal (Once) Tightened (trail)	Start of Ortho-correction
9	Comparison of DEMs with vertical checkpoints (if available, AT vertical points)	Sample	First DEM	Start of Ortho-correction
10	Residuals of block adjustment on control and check points	100%	Normal (Once) Tightened (trail)	After AT (Orthoimage production)
11	RMSE of finalised block adjustments using contractors' check points, including individual residuals	100%	Normal (100% of blocks)	(After AT) Orthoimage production
12	Ortho-image metadata	100%	Normal (10%) Tightened (100%)	Start of Orthomosaic production
13	Ortho-images (inspection result)	100%	Normal (10%))	Orthoimage production

Table 6. QCR Production and Use for Aerial Ortho-images

8.5 Updating of zones covered by existing orthophotos

Two strategies are considered applicable for the updating of zones with existing orthophotos:

- Use of GPS controlled flight: repeat of (automated) aerotriangulation
- Model-based approach, using ground and photo point data used in initial orthophoto creation

Both approaches make use of existing ground control and DTM/DEM data: thus significantly reducing the required re-visits in the field. Where the terrain has changed the DTM/DEM should be edited. Such areas may be detected with correlation techniques from new flights and a comparison with the existing DEM/DTM and orthophotos.

Since many of the steps for production are the same as for the initial creation, these are not re-specified here; reference is made to the preceding sections. However, the revision flight should be compatible with (although not necessarily identical to) the initial flight, hence a preference for GPS controlled/pin point execution.

Furthermore, a technical preference based upon quality considerations reinforces the application of a GPS based flight, with a full aerotriangulation and block adjustment, over the model-based approach. Again, this introduces no new technical considerations not treated above, so no further details are included here; internal quality assurance will be expected to comply as previously described.

Where a dense GCP network of sufficient quality (see Table 4 above) already exists, an alternative approach can be to produce orientation parameters by model but it should not considered as 'best practice'.

In all cases, final acceptance will be made by applying the external quality control guidelines detailed in Chapter 12.

9 Satellite Image Correction QA

9.1 Introduction

This section outlines the process of creating digital orthoimages from satellite imagery. The chapter will refer to systems with a standard pixel size of

- <3m as "Very High Resolution" (VHR),
- 3-8m as "High Resolution" (HR).
- 10-20m as 'Medium Resolution' (MR)
- >20m as 'Low Resolution' (LR)

Note that, with the consideration now of VHR and HR data orthorectification, many of the minimum ancillary data (DEM, ground control etc.) requirements are now roughly equivalent to those for aerial photography processing.

9.2 Input data

Satellite sensors have a very narrow field of view (FOV) compared to the airborne so that in principle the effect of the DEM error on the produced orthophotos could be reduced almost to zero if images are collected as close to nadir as possible. However in practice the sensors can rotate (flexibility and revisit) and most of the space imagery is collected with off-nadir angle. It is therefore important to ensure that the DEM used for the orthorectification (existing or produced) will be of sufficient accuracy (Figure 2).

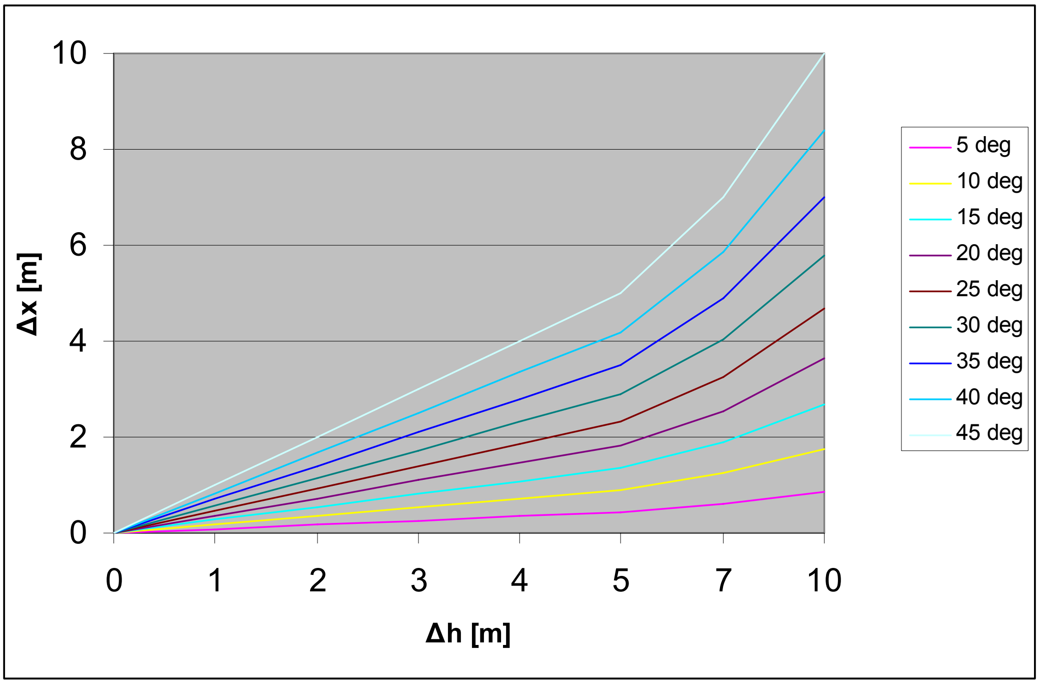

Figure 2. Influence of off-nadir angle and DEM accuracy (Δh) to the accuracy of the orthophoto (Δx)

The image quality control record requirements are outlined in Table 7.

Item	Requirement	Internal QCR/QA
Image Check	Image must be readable and image visual quality must allow accurate GCP placement.	Confirm image can be read by displaying it on-screen. Note any format or other quality problems (e.g. low sun angle, quantisation, haze, cloud cover). See also radiometric QA (6.3)
Orientation information and metadata	Data provided with the image must include additional information to allow ortho-correction (RPC coefficients, view angle, orbit model, etc.).	Note the input product level; generally no geometric processing is desirable beforehand. Confirm compatibility with the correction software.
DEM	For height accuracy see Figure 2 The DEM should be of sufficient detail, complete, continuous and without any gross anomalies. QC should confirm that the DEM is correctly georeferenced and elevations have not been corrupted or accidentally re-scaled during re-formatting/preparation. Attention should be paid to datum references (mean sea level vs. ellipsoidal heights, for example)	Vertical accuracy of the DEM must be checked by comparison against independent control Visualise on-screen (e.g. contours, shaded relief). Possibly use histograms/3D views to check for spikes/holes. Look for completeness in the project zone and continuity along tile boundaries. Overlay available map data to check georeferencing is correct. Check corner and centre pixel values against heights on published maps.

Table 7. QCRs for Geometric Correction of Satellite Images

Raw Image formats suitable for orthocorrection are those which in general have had no geometric pre-processing.

9.3 Ground control requirements

The requirements of the ground reference data described in Chapter 7 apply also for the satellite image orthorectification.

Table 9 gives guidance as the number and distribution of GCPs required for different images and orthocorrection methods.

9.4 Geometric correction process

Most orthoimage rectification in the scope of EC work is carried out with respect to national mapping or land parcel systems of high geometric precision (1:1,000-1:10,000). Images are corrected to their absolute position, and only in rare cases will images be corrected to a "master image" in a relative manner (for example, without formal projection systems). The only notable exception to this is when a VHR image is used as a reference for other, lower resolution images; in general, the pixel size should be at least 3 times bigger than the VHR image.

For **VHR imagery** orthocorrection will be required in most cases. Polynomial correction with VHR images will only provide acceptable results only in a few restricted circumstances of flat terrain. In practical terms, planning and provision for the orthocorrection will mean that this choice will rarely be made.

For **HR, MR, LR image**s a decision may be required as to whether a particular image should be corrected by ortho-correction or polynomial warping (Table 8).

Image/Terrain	Correction Procedure
HR: Terrain variation > 250m over whole image	Generally orthocorrect (For large image area, piecewise warping could be possible)
HR: View angle at centre of image > 15° from nadir	Generally orthocorrect (For flat image area, warping could be possible)
MR and LR images	Polynomial warp generally acceptable but terrain variation is critical

Table 8. Geometric Correction Procedure choice for HR,MR and LR images

Generally, the number of GCPs required when using the recommended approach (using vendor-supplied RPCs) is as few as 2-4 GCPs per image scene but it also depends on the length strip and the linearity of a specific system (e.g. QB). The distribution of the GCPs is not usually critical (e.g. IK) but well distributed preferred.

In case of large off-nadir angles and terrain variations, it is preferred to deliver separate RPC files for each standard image forming the strip, which will represent more accurate the exterior orientation of the sensor at the time of acquisition of each scene.

As an alternative to single scene processing, and if appropriate software is available, multiple image scenes – or a "block" of images – for the same zone can be processed together to calculate the best fit for all images. It is not recommended to use less than one GCP per single scene in the block.

Table 9 provides a summary of this guidance and tolerance specification for each stage of the satellite orthocorrection process. The measurements corresponding to each tolerance should be used to provide quantitative input to QCRs.

Stage	Practical procedure	Acceptable tolerance
Orbit model	No check required.	Present in header information
GCP selection, HR,MR,LR (e.g. SPOT, IRS, Landsat)	GCPs should be well distributed (in grid) with points as near as possible to each corner/edge (no extrapolation).	Polynomial warp: > 15 GCPS per scene. Physical model orthorectification (at least 9 GCPs per scene)
GCP selection, VHR with vendor supplied RPC processing	Recommendation is to use supplied RPC data and 4 GCPs located in the image corners. For strip scenes, additional control should be used (e.g. Ikonos, Quickbird).	Minimum, 2 - 4 per scene, additional GCPs could be needed due to strip length and the linearity of the system (e.g. plus 2 per additional 100km^2 of strip scene) Generally GCP distribution not critical, but well distributed preferred.
	For VHR block processing (multiple scenes), ground control may be reduced up to 1 GCP per scene if sufficient good tie points available between imagery	GCP preferably fall in overlap zones (image corners) but not critical
GCP selection, VHR with physical model RPC generation from ground control	VHR orthorectification using a physical sensor model usually requires more GCPs (than RCP), depending on the specific sensor. This method should not to be used (non reliable and GCP intensive).	More than 4 GCPs (depending on the unknowns).per scene. Distribution of GCPs should cover full AOI.
GCP Blunder Check	Residuals should be calculated when redundancy available in GCPs; otherwise check independent points.	Maximum residual should not exceed 3 x the target RMSE.
Polynomial warp (only)	Use a first or second order polynomial, third order must not be used.	Record the polynomial order in the metadata/QCR.
Rectification results	Calculate RMSE discrepancy on 10 independent check points per image (if available) OR Record the prediction sum of squares (PRESS) – if available. Record the residuals and RMSE for each GCP compared to the fitted model.	Checkpoint RMSE < tolerance for geometric accuracy. √PRESS < tolerance for geometric accuracy. RMSE if calculated on residuals should < 0.5 x tolerance for geometric accuracy: Save GCPs/residuals to file

		Record summary results in metadata/QCR.
Resampling	For imagery unlikely to be quantitatively analysed/ classified bilinear interpolation or Cubic convolution is appropriate; output pixel size ≅ input pixel size. Nearest neighbour may be used if justified (e.g. classification), but output pixel size should be 0.5x input pixel size.	Record resampling method and output pixel size.
Visual accuracy check	Overlay digital map data on the image and inspect systematically	Independent check by supervisor. Log Pass/Fail and inspection date for this image in QCR.
Accuracy of the master image	Measure the accuracy of the master image using check points which were not used as GCPs during geometric correction.	Minimum of 20 check points distributed on a regular grid. Accuracy: 3 x tolerable RMSE. File dated record of the check results. Record result in metadata and identify as master image.

Table 9. Specification for Satellite Image Rectification

9.5 QCRs and quality audits for satellite image rectification

A file naming convention should be introduced and a meta-database developed which allows the following information to be associated with each image product and any supplementary files (e.g. GCPs, checkpoint results):

- Image ID, Master Image ID, Project site ID, Sensor, Acquisition date, View angle or beam number, Cloud cover, Product level, Initial QC (OK/Problem), Pre-processing (e.g. filtering), DEM grid size or average distance, DEM accuracy, Result of DEM QC.
- Software Used, Blunder check completed, Number of GCPs, Residual RMSE(metres), √PRESS(metres), Correction method (poly, ortho), Order of Polynomial, Resampling method, Output pixel Size, Number of checkpoints, Checkpoint RMSE, Maximum Checkpoint Discrepancy, Production Date, Comments, Operator name.

Further information should include:

- input and output file names, sources of ground control, projection details, detailed results of the DEM checks, corner co-ordinates and result of visual QC signed and dated by a supervisor.

It is strongly recommended that a paper *pro-forma* designed to record all the information listed above is devised by the contractor, there should be one form for each output image and the relevant data from these can then be entered into the metadata database.

A procedure should be applied to ensure that the final product is clearly labelled as such and that the information retained in the QCRs is that which applies to this final product

Contractors will generate the QCRs identified above for their Internal QA. They should be made available for inspection during a quality audit. The type of quality audit is shown in Table 10 as “Normal” or “Tightened” (see 2.3).

QCR	Contractor Production Level	EC Inspection Level (Sample)	EC Audit Stage
Image Check (esp. view angle record)	100%	Tightened (trail)	Any time
DEM (esp. anomalies and height accuracy)	100%	Tightened (trail)	Any time
Ground reference data	100%	Tightened (trail)	Any time
Software	-	Normal (once)	Before any correction
CV/Training certificate for operators	-	Tightened (trail)	Any time
File of GCPs, check points and residuals (used for Internal QC)	100%	Tightened (trail)	Any time
Adjustment/warp results	100%	Normal (first few) Tightened (trail)	Any time
Resampling	100%	Tightened (trail)	Any time
Visual accuracy check	100%	Normal (Once) Tightened (trail)	Start of Image-correction
Accuracy of the master image	100%	Normal (100%)	Start of image production on each site
Image metadata	100%	Normal (100%)	Start and end of image production

Table 10. QCR Production and Auditing for Satellite Image Rectification

10 Image fusion (Pan-Sharpening)

10.1 Introduction

Image data fusion has become an important topic for various applications. It might be related to the fusion of different type of images from same sensor or images from different sensors. Thus more and more general formal solutions are needed. Many issues in image processing simultaneously require high spatial and high spectral information from a single image. This is especially important in the remote sensing. However, in most of the cases, instruments are not capable of providing such information either by design or because of observational constraints. A possible solution for this is the image data fusion.

10.2 Requirements for fusion products

Aspects (of relevance) regarding to the standardization and to the quality assessment of image fusion (results), irrespective of the applied algorithm, (do not appear in many published papers) are not widely covered in the literature. The following fields of requirements can be determined:

- Requirements for utilised sensors
- Requirements for methods and quality of co-registration
- Requirements for spatial image quality (e.g. from point spread function analyses) and
- Requirements for radiometric and colour quality (for true colour image data)

10.3 Enhancement of spatial resolution

A quality criterion for pan-sharpening methods is the preservation of the spatial resolution of the panchromatic image in the end product. This can be evaluated by analysis of the point spread function by means of distinctive image structures.

Another quality criterion for the pan-sharpening process performance is the number of visible artefacts. Especially problematic are object edges, if the red, green and blue bands are not accurately co-registered.

10.4 Preservation of spectral features

Spectral features of the original low-resolution image need to be preserved in the generated high-resolution multispectral image in order to be in the position to adopt e.g. classification algorithms successfully. A modification of the colour distribution in the end product compared to the reference image can be roughly endorsed by comparison of the histograms of the red, green and blue proportions of the individual images. More differentiated assessment of the preservation of true colour features in the original and the pan-sharpened images can be carried out by applying colour-distance in Lab-space (Wyszecki and Stiles, 2000).

10.5 Pan-sharpening of satellite data

The information given bellow is more oriented to the problems of pan-sharpening of VHR (spaceborne) data, in particular:

VHR (PAN)+VHR (MS) or

VHR (PAN)+HR(MS)

In any case, the data fusion of any other kind of spaceborne data (HR+LR, HR+HR, etc.) follows in principle the same rules mentioned here.

10.5.1 Geometric pre-processing

One of the key points to obtain spatially and spectrally enhanced image, through resolution merge, is the proper co-registration of the different image datasets. With respect to the satellite data, the following main cases could be outlined:

- resolution merge of data with different resolution, obtained by the same satellite at the same time:

  Both satellites are considered to have the PAN and MS images *almost* acquired simultaneously[3]. Therefore, in order to obtain sufficient results, it is essential that the same geometric model for orthorectification is used for both the PAN and the MS raw image. The GCPs used, should be exactly the same for both PAN and MS images.

- resolution merge of images with different resolution, obtained by the same satellite at different time:

  This is for example the case of VHR satellites, providing bundle products, which do not acquire simultaneously the PAN and the MS components. The GCPs used for the orthorectification, should be exactly the same for both PAN and MS images.

- resolution merge of images with different resolution, obtained by different satellites:

  When VHR (PAN only) sensors have to be combined with additional HR, the following temporal and geometric factors should be considered:

  - The PAN and MS component will be acquired separately in different weather conditions and with different viewing angles
  - They will not have same Field of View and exterior orientation, as they belong to different sensors
  - They might represent different vegetation status, due to larger time gap in the acquisition
  - The spatial resolution of the HR might be too coarse for the combined use with VHR PAN

10.5.2 Radiometric pre-processing

The most common task performed prior to the resolution merge is the rescaling of the image DN values. Usually, the radiometric depth of 8 bits is considered enough to ensure efficient handling of the data without significant loss of information. The raw VHR (both PAN and MS) is usually delivered by the provider as 16 bit (in reality, it is 11-bit for IK and QB), which is rescaled to 8 bits in order to save disk space and increase the performance of the processing.

The type of conversion to 8-bit format should be carefully considered. The use of the Standard Deviation stretch on the look-up table is the most common approach, with a setting between 2 and 3 standard deviations (up to the operator). An important point is to exclude the zero values, when calculating the statistics of the rescaled image.

10.6 Pan-sharpening Algorithms

There are many pan-sharpening algorithms available today in commercial packages. Some of them are:

- HIS Sharpening. HIS stands for "Hue Intensity Saturation". The low resolution RGB image is upsampled and converted to HIS space. The panchromatic band is then matched and substituted for the Intensity band. The HIS image is converted back to RGB space.

- Brovey Transform. The Brovey Transform was developed to visually increase contrast in the low and high ends of an image's histogram. It is a simple method to merge data from different sensors.

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[3] Random spacecraft motion between collects can cause misregistration between the pan and MS bands, which results in a blurry pan sharpened image. In addition parallax between the bands can cause misregistration, especially when there are errors in the elevation model.

- **Multiplicative.** The multiplicative algorithm is derived by using the four possible arithmetic methods to incorporate an intensity image into a chromatic image (addition, subtraction, division, and multiplication).
- **PCA Sharpening.** Principal Components Analysis is based on a rotation in which the covariance matrix becomes diagonal (all off diagonal elements are zero). The 1st principal component (PC) contains most of the information. The panchromatic band is substituted in for the 1st principal component. Image is rotated back to original space.
- **Gramm Schmidt Sharpening.** This is a Kodak / RSI proprietary sharpening algorithm. The algorithm is based on a rotation similar in nature to PCA. The results are quite similar to PCA – robustness is an issue especially in heavily vegetated scenes
- **Wavelet Sharpening.** A relatively new sharpening algorithm involving wavelets has come into use lately. The low resolution RGB image is upsampled to match the panchromatic resolution, then converted to HIS space. High frequency information from the panchromatic band is extracted and added to the intensity band. The result is converted back to RGB space
- **UNB Sharpening.** UNB stands for University of New Brunswick. Algorithm is proprietary and was developed by Dr. Yun Zhang at UNB. This algorithm has been licensed by both DigitalGlobe and PCI (latest version of Geomatica). This is DigitalGlobe's most popular pan sharpening algorithm to date.

11 Mosaicking

Mosaicking is used for producing a visually appealing orthoimage of large areas. In order to achieve this goal, the input images should have consistent geometric and radiometric characteristics so that the seams will be as less visible as possible in the output mosaic. Table 11 presents the main steps of the process and the quality checks to be followed.

Operation	Best practice	Quality check
Radiometric pre-processing	Input images should be radiometrically homogeneous Mosaic as much as possible only images acquired in a single collect (same conditions)	Images should be contrast, lightness (and colour) balanced Similar types of objects not varying more than 10% in DN value (average).
Area selection	The most nadir chips of the images should be used for mosaicking to reduce distortion effects (smear)	Check the seamlines against the image nadir points and footprints
Seamlines	Run batch process with automatic seam generation but with user interaction for reviewing and editing seamlines	Visual check for full coverage at the AOI with seamlines polygons Seamlines not to cut through well defined features (e.g. buildings especially if not a DSM used) Visual check along seams for geometric discrepancies or feathering effects (blur)

Table 11. Best practice and QC for the production of orthomosaics.

The final mosaics (usually tiled) should be accompanied with the following metadata:

- A shapefile of the seamlines polygons and the information regarding with the input images (see 5.3)
- A shapefile of the tiles distribution and their attributes
- Analytical information about the radiometric processing of the input images

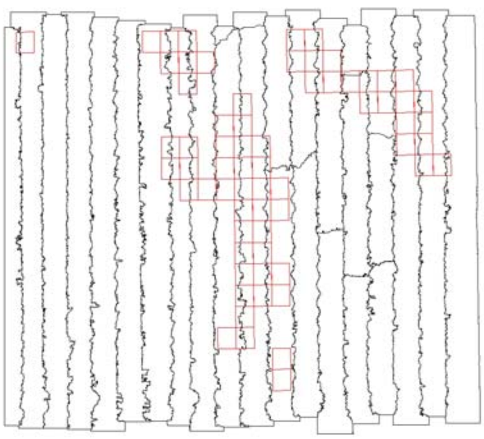

Figure 3. Seamlines polygons and tiles distribution (NAIP 2007 Arizona Preliminary Seamline Shapefile Inspection)

12 Method for External Quality Checks

12.1 Introduction

This chapter describes a method for independently checking the accuracy of orthorectified images and the associated DTMs. The radiometric quality check of the orthoimages will be similar to that applied for the images (see 6.3).

The check is **intended to be carried out independently** by a separate contractor (or in collaboration with the original contractor) using a sample of the final products provided by the contractor carrying out the geometric correction work. It may, however, depend on products from the original contractor.

12.2 Thresholds and QC checks

In general, the final orthoimage will be assessed from the geometric perspective of RMSEx and RMSEy and the associated DEM from RMSEz. The use of RMSE provides a straight forward, easy –to-compute global statistic for assessing the final geometric accuracy.

Additional indexes such as the mean error and the error standard deviation can be used in order to better describe the spatial variation of errors or to identify potential systematic discrepancies.

Finally visualisation tools and techniques like histograms or plots of residuals can be very helpful. In the case of DEMs visualisation techniques (shaded relief, contours, remainder image) are considered as necessary tools for checking completeness and for gross errors detection (Oskanen, 2006).

Product deliveries determined to be outside this specification will be returned to the contractor for evaluation (internal QA) and redelivery, followed by further (possibly repeat) checks (external QA).

12.3 Digital image delivery:

The Commission will check according to the criteria specified in Chapter 6 (and 9.2) at least a sample (minimum 10%) of the images delivered. If on this sample test, more than 5% of the images tested fail on one or more of these specifications, the entire delivery may be returned to the contractor for quality checking and re-delivery. In other cases, imagery failing the specification on one or more of the tests may be required to be re-processed until the specification is met in full.

12.4 Inputs to orthocorrection external quality check

For the external checking of orthoimage accuracy the following information is required as input.

Item	Specification	Format
Ortho-image	Selected extracts from the final products, georeferenced to the (national) map projection.	Digital format (as agreed in specification)
Mosaic description	Record of the location of seamlines for the mosaics (see 11)	Shape file
GCPs	Document listing the GCP id and coordinates: Short text explaining how the GCPs were collected (equipment, vertical and horizontal control(s) used), estimated precision and accuracy (see.7.3) Image extracts clearly marked with precise GCP locations and identifiers.	Hardcopy and softcopy (ASCII, Tab delimited) or GIS layers. Document with image extracts showing position and coordinates
Check points (acquired independently)	The same as for GCPs above Generally a minimum number of 20 well-distributed Check Points per site is necessary in order to apply reliable statistic tests (Figure 4).	The same as for GCPs above

Table 12. Inputs to External QC of orthoimages

The checkpoints should be provided from a different source than the contractor; however, QCR information may permit use of contractor data where these show that the data are reliable (although it is not recommended).

Generally around 5-10% of orthoimage files will be checked externally. Product files will be selected on a systematic basis to ensure that:

- QC is well distributed within the block/site area
- areas with different terrain relief and land cover will be included
- areas where problems are anticipated will be checked (e.g. known quality problems with specific batches of original photos high view angles, etc)

Additional blocks/images will also be selected on a random basis.

The results for separate photos will be analysed together as a guard against systematic errors.

12.5 Check point selection and distribution

Conformance with tolerances will be assessed on a sample of images using independent measurements of image accuracy (i.e. not the GCPs used for correction). With regard to CPs accuracy tolerances, selection criteria and documentation requirements see chapter 7, Ground reference data.

The check points will be (ideally) evenly distributed and located across the image (Figure 4). The selected check point positions may be (re)located with reference to the positions of the GCPs used to correct the imagery in order to ensure that the two sets of points are independent (CPs should not be close to the GCPs).

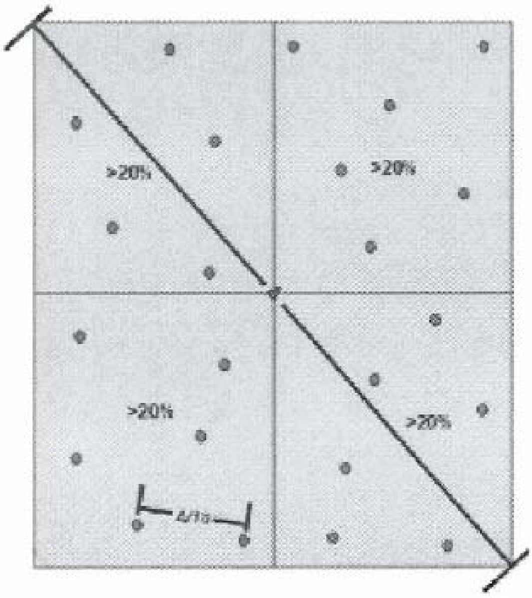

Figure 4[4]. Distribution of CPs in the area to be checked. At least 20% of the points should lay in each quarter whereas the optimum distance between points (is related to the diagonal distance of the area (1/10th of Δ)

12.6 External quality checking method for image accuracy

The operator identifies the location of each checkpoint on the image and enters this and the 'true' co-ordinate in a table. A discrepancy is then calculated for each checkpoint together with an overall RMSE. These calculated values are then compared to the project tolerances and a 'Pass' or 'Fail' status applied to the final result. The operator applies a 'Fail' to an image where the calculated RMSE is greater than the tolerable RMSE entered. Normally the tolerable RMSE will be the same as the tolerable RMSE specified in the ITT or contract.

The concept of *maximum tolerable discrepancy* is defined as three times the calculated RMSE. A point that exceeds the maximum tolerable discrepancy may be considered as a blunder error if further inspection of the point reveals that this decision is justified (type of point, uncertainty of location,

4 The figure is copied by the 'Notes for students on photogrammetric quality control' of AUTH (Prof. Patias)

etc.). In addition, justification for the elimination of such a point must be documented (equipment failure, change of feature between photography and survey, etc.). No point that is within the maximum tolerance may be eliminated from the sample dataset.

The recommended output is a report showing an analysis of the results. A text page contains a table of check points with the individual discrepancy between the image and their 'true' location, together with the 'Pass' or 'Fail' status and summary statistics (mean error in x and y, standard deviation, RMSEx, RMSEy, maximum discrepancy). A graphical report shows the position of each checkpoint relative to the grid, together with the size and direction of the discrepancy.

Figure 5 is an example of the output showing checkpoint distribution and discrepancies (in this case for a SPOT image; the principle for aerial photography analysis however remains the same).

12.7 Result calculation - within block

A block is normally considered to be a **geometrically homogeneous group of image products** (orthoimage, DEM), such as a photogrammetric aerotriangulation block, or RS Control site. However, in the case of orthoimages created by space resection (either per image or per photogramme), each will be treated as a block.

The absolute RMSE of all check points in the block/site will be calculated[5]: should this exceed the project specification, **all products** associated with the block/site will be rejected. However, further investigations may be necessary to increase confidence in the result should the final result be marginal (just below or above the tolerance). These may involve the acquisition of further points, or may involve the follow-up of specific production problems (tightened auditing checks).

The planimetric threshold will be **applied independently** in X, and Y. Failure to meet the specification in either of these two dimensions (i.e. RMSEx or RMSEy) will reject the block.

Where the DEM is also a deliverable in the contract, the **DEM will be checked using the Z threshold** tolerance. Again, exceeding the RMSEz tolerance will reject all products for the block.

12.8 Result calculation - project level

At least 10% of the sites or photogrammetric blocks will be independently checked following the method outlined above. **All blocks** that fail will be examined by the contractor, corrected, and redelivered.

Should **more than 5% of the blocks that are subjected to external QC fail**[6], **all products** will be returned to the contractor for further QA. In effect, the Commission will pass responsibility to the contractor to provide adequate and clear internal Quality Audits to identify the extent and cause of the problems so established. The contractor will be expected to rectify these problems, and (where necessary to comply with the specification) make new products.

Redelivery of products will be followed by a further independent check on a new sample[7] of the products. This procedure will continue until the products are finally acceptable under the terms above.

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[5] Although in the case of RS Control sites with differing image resolutions, these may be computed separately.

[6] For projects where space resection has been used in the production of individual orthophotos should any block fail, the dataset will be subject to redelivery.

[7] Which may include the existing data acquired for external QC.

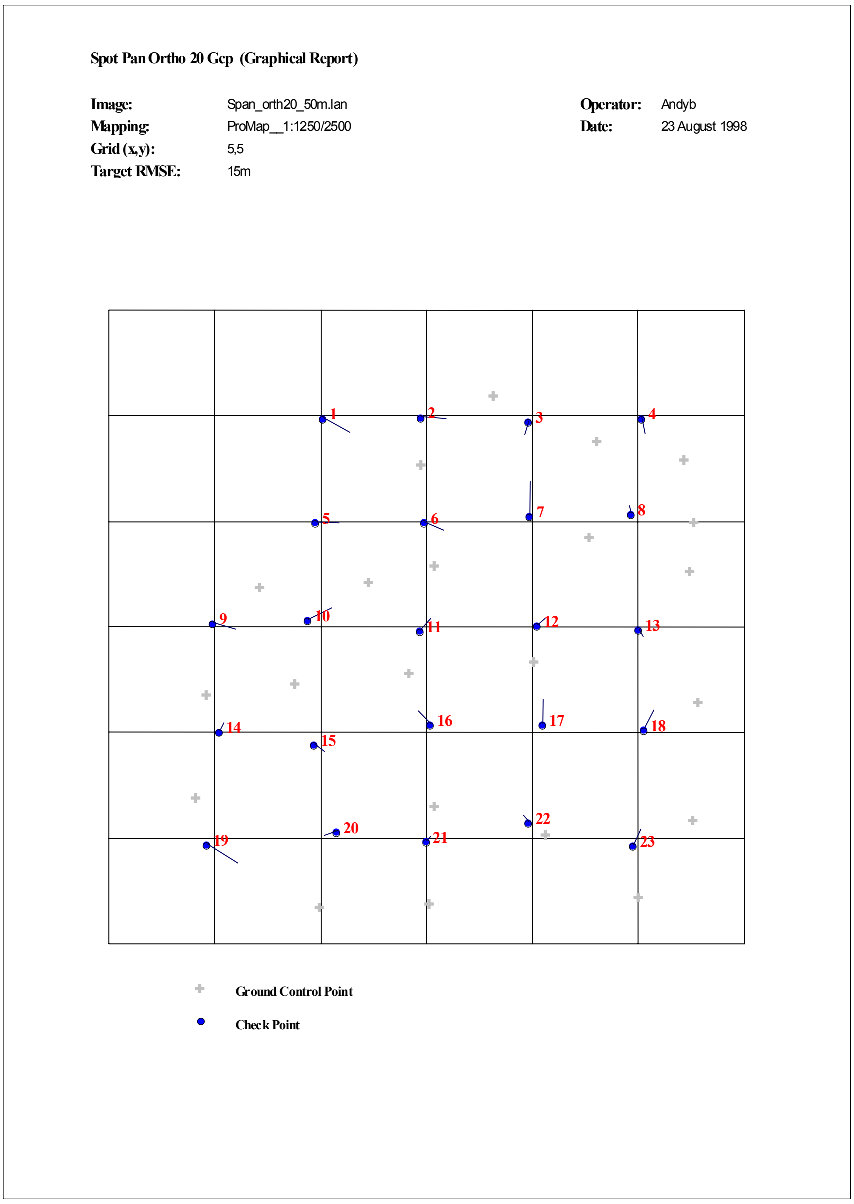

Figure 5. Output from External QC Showing Check Points, Discrepancies and GCPs

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Acronyms and Abbreviations

ASCII	American Standard Code for Information Interchange
ASPRS	American Society of Photogrammetry and Remote Sensing
AT	Aerotriangulation
BI	Bilinear Interpolation
CAPI	Computer Assisted Photo-Interpretation
CC	(bi-)Cubic Convolution
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DPW	Digital Photogrammetric Workstation
EC	European Commission
ERS	European Remote Sensing Satellite
EU	European Union
GCP	Ground Control Point
GIF	Graphics Interchange File
GIS	Geographical Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HR	High Resolution
IACS	Integrated Administration and Control System
IDQA	Input Data Quality Assessment
IRS	Indian Remote sensing Satellite
ITT	Invitation to Tender
NN	Nearest Neighbour
OS	Operating System
LPIS	Land Parcel Identification System
PRESS	Prediction Error Sum of Squares
QA	Quality Assurance
QC	Quality Control
QCR	Quality Control Record
RF	Representative Fraction
RMSE	Root Mean Squared Error
RSAC	Remote Sensing Applications Consultants
SAR	Synthetic Aperture Radar
SNR	Signal to Noise Ratio
SPOT	Satellite Pour l'Observation de la Terre
TDI	Time Delay Integration
TM	Thematic Mapper
TM	Transverse Mercator
UCL	University College London
VHR	Very High Resolution
WP	Work Package

Definitions

Within the separate literature on geometric correction of satellite images, map accuracy assessment and photogrammetry, different terms are sometimes assigned the same meaning when they can usefully be assigned more precise and distinct meanings (e.g. discrepancy and residual). The following definitions *apply to terms as used in this document* and have been phrased, where possible, to be applicable both to air-photo and satellite image correction. Cross references to other definitions are indicated with italics.

Term	Definition	Adapted from
Accuracy	Accuracy is the relationship of a set of features to a defined reference system and is expressed as a multiple (1 or more) of the *rms error* of a set of derived points (if possible expressed as a ground distance in metres, but sometimes given as pixels or microns).	
Aerotriangulation	The process of aerial triangulation is the densification of geometric control to the individual *stereomodel* level by the identification of ground co-ordinates for *tie points* based on the network of known survey data. This process computes a project-wide network of control and confirms the integrity of the *ground control points*.	Wolf 1983
Blunder	See *Error*	
Block, block processing	Two or more image strips (or *image frames*) having a lateral overlap, usually a set of aerial images or a set of VHR *image scenes*.	Wolf 1983
Check Point	A well-defined *reference* point used for checking the *accuracy* of a *geometrically corrected* image or image mosaic. The location accuracy of the check point must exceed the tolerable accuracy of the image by a factor of at least three. Check points must not be the same as *GCPs*.	Wolf 1983
COTS	Commercial Off The Shelf (software)	
Digital Elevation Model	A digital, raster representation of land surface elevation above sea level. DEM is used in preference to digital terrain model (DTM) because the term 'terrain' implies attributes of the landscape other than elevation.	Burrough 1986 p39
Discrepancy	A discrepancy is the linear distance between a point on the image and a *check point*. A discrepancy is not the same as a *residual*, because a discrepancy is an *error* at each point measured using a reference point known to a higher order of accuracy.	
Ellipsoid	For conversion to a flat surface (ie for mapping), a projection process is applied to a world reference system (*Geodetic Datum*) with its associated ellipsoid. Ellipsoidal models define an ellipsoid with an equatorial radius and a polar radius. The best of these models can represent the shape of the earth over the smoothed, averaged sea-surface to within about one-hundred meters. WGS 84 is a standard for the whole world but may give not an exact fit in a given area.	Dana, 1998
Error	Geometric error in an image which has been corrected to fit a map projection. Three classes of error are commonly recognised: A <u>random error</u> is not predictable at any given location but the population of random geometric errors commonly follows a normal (Gaussian) probability distribution. If random errors are normally distributed the mean error is zero for a large sample of points. A <u>systematic error</u> is predictable at any given location once it has been identified and its pattern of variation is understood. For a large sample of points, a mean error that is not zero can sometimes indicate presence of a systematic error. A <u>blunder</u> is a (large) error at one location arising from a mistake or equipment fault whilst marking the location or recording its coordinates. An error at a single	Harley, 1975

	point that exceeds 3 x RMSE of a sample population is usually due to a blunder.	
Exposure Station	The 3D position of an aerial camera at the time of film exposure, projected XYZ; typically given by GPS, or post-AT.	Adapted from Wolf 1983
Geocoding	Synonym for *orthorectification*, but more commonly used when discussing SAR data. Generally avoided here because the same word is also used for automatic postal address matching in GIS.	
Geodetic datum	When an *ellipsoid* is fixed at a particular orientation and position with respect to the Earth, it constitutes a so-called `Geodetic Datum'. WGS 84 is one such Geodetic Datum. An ellipsoid itself is therefore insufficient to define a Geodetic Datum, the position and orientation of the ellipsoid to the Earth need to be defined also.	Dana, 1998
Geometric correction	Informal term for *rectification.*	
Georeferencing	The process of assigning ground coordinates to an image. The image grid is not changed by this process.	
Ground control point	A well-defined point used for orientation and *rectification*. The position of a GCP is known both in *ground reference* co-ordinates and in the co-ordinates of the *image* to be corrected. If 2D (x,y) ground reference co-ordinates are given, it is a horizontal or planimetric GCP; if the height (z co-ordinate) is known, the point is a vertical GCP.	
Ground Reference	The source used to obtain ground reference coordinates for a *ground control point* or *check point*. May be a topographic map, a field survey by triangulation, a geodetic bench mark, a field survey by GPS, or a *geocoded image*. Ground reference coordinates are given in (or converted to) the national map projection.	
Image	A digital Earth observation picture in raster form may be scanned from an aerial photograph or produced directly from a digital airborne or satellite sensor.	
Image Frame	A unit of image acquisition with a single set of orientation parameters. When referring to satellite, the image frame is called usually "scene" or "strip"	
Image Fusion	Image fusion is a concept of combining multiple images into composite products, through which more information than that of individual input images can be revealed.	
Interpolation	Method used to estimate a pixel value for a corrected image grid, when re-sampling from pixel values in the original grid. Common methods are nearest neighbour, bilinear interpolation and cubic convolution.	
Maximum Tolerable Discrepancy	Defined as three times the RMSE of the check point sample: is used to help determine if a point can be considered as a blunder error.	
Model	Abbreviation of *Stereoscopic Model*	
Orientation	Orientation can have two or three stages. <u>Interior</u> orientation establishes precise relationships between a real *image* and the focal plane of a perfect imaging system. <u>Relative</u> orientation establishes precise relationships between the focal planes of a perfect stereopair to establish a precise *stereomodel* <u>Absolute</u> orientation establishes a precise relationship between the *stereomodel* and a geographic reference system (map projection). Absolute orientation follows relative orientation. <u>Exterior</u> orientation establishes precise relationships between the focal plane co-ordinates and a geographic reference system (map projection). It can be achieved by relative and absolute orientation or can be carried out in a single step.	
Orthorectification (orthocorrection)	*Rectification* of an image (or image stereo pair) using 3D *ground reference* and a DEM to position all image features in their true orthographic locations. The process eliminates displacements due to image geometry (especially tilt) and topographic relief, and results in an image having the same geometric properties as a map projection.	Wolf 1983

Pass point	A synonym for *tie point*.	
Pixel size	Distance represented by each pixel in an *image* or *DEM* in x and y components. Pixel size can be expressed as a distance on the ground or a distance on scanned hardcopy (e.g. microns). It is not a measure of *resolution*.	
Point spread function (PSF)	The point spread function (PSF) describes the response of an imaging system to a point source or point object. Another commonly used term for the PSF is a system's impulse response. The PSF in many contexts can be thought of as the extended blob in an image that represents an unresolved object.	
Polynomial rectification (also called Warping)	*Rectification* of an image to a *ground reference* using horizontal *ground control points*. It assumes that the local distortion of the image is uniform and continuous since it ignores effects of terrain.	
Precision	The precision of a *GCP* or *check point* is the standard deviation of its position (in x, y and z) as determined from repeated trials under identical conditions. Precision indicates the internal consistency of a set of data and is expressed as the *standard deviation*. Note: Data can be precise yet inaccurate; precision is not used when comparing a set of data to an external reference, *RMSE* is used to express this.	
PRESS	The cross validation estimate, also referred to as the Prediction Sum of Squares (PRESS) statistic. In this statistic the best-fit model is refitted 'n' times. Each time it is fitted to a subset of the GCPs from which one point has been removed. By using the best fit to all the other points, the predicted location of the omitted point is computed and the difference from its actual location is then obtained. The average of these squared differences computed on the complete set of 'n' differences is the PRESS value and the square root provides a figure in the measurement units of the residuals.	
Rectification	The process of resampling pixels of an image into a new grid which is referenced to a specific geographic projection, using a spatial transformation (matrix). The resampling is achieved through *interpolation*.	
Registration	*Rectification* of an *image* to conform to another *image*.	
Residual	A residual is the linear distance between a fixed reference point [ground control point] and the position determined by the transformation applied to the observed data to give a best fit to the reference points. Note: This is not the same as a *discrepancy* because the computed error of a residual is based only on the internal (statistical) consistency of a set of points and not on comparison to independent locations known to higher accuracy.	
Resolution (resolving power)	The smallest visible separation between similar objects that can be clearly reproduced by a remote sensing system – usually expressed as the maximum number of line pairs per unit length.	Light 1993
RMS Error	The square root of the average of the squared *discrepancies* or *residuals*: $\sqrt{\frac{1}{n}\sum_1^n d_n^2}$ where d is the measured discrepancy or residual in x, y or z. For small samples (n < 30) or if systematic error is present this is not the same as the *standard deviation* of the discrepancy.	ASPRS 1989
RMSE (Absolute)	*RMSE* based on *check points* obtained from a *ground reference* of recognised higher *accuracy*.	Adapted from EC 1997
RMSE (Relative)	*RMSE* based on *check points* extracted from another *geocoded image*. In practice the RMSE of the GCP *residuals* is also used as a measure of relative error.	Adapted from EC 1997
Standard Deviation	The square root of the variance of n observations, where the variance is the average of the squared deviations about the estimate of the true mean value.	

	$\sqrt{\sum_{i=1}^{n}\frac{(x_i-\bar{x})^2}{n-1}}$ For small samples (n < 30) this is not the same as the *rms error*. If there is no *systematic error*, standard deviation is equal to the *RMSE* for large samples.	
Stereoscopic Model (or Stereomodel)	Three-dimensional model created by viewing or analysing the overlapping area of two *images* obtained from different positions.	
Tie points	Points that appear on the overlap area of adjacent images. They are used for *orientation* and *aerotriangulationor block processing*. In general are not measured on the ground and only image coordinates are used	
Tolerance	The tolerance is the permissible degree of *error* in a geometrically corrected *image* or mosaic as determined using a well distributed set of *check points*. Tolerance is specified with one value: the maximum allowable *RMS error* of all check points	
Warping	Synonym for *Polynomial Rectification*	
Well-defined point	A well-defined point represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum. For the purpose of accuracy testing, well-defined points must be easily visible or recoverable on the ground, on the independent source of higher accuracy, and on the product itself.	FGDC, 1998

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Abstract

For almost 10 years JRC's "Guidelines for Best Practice and Quality Control of Ortho Imagery" has served as a reference document for the production of orthoimagery not only for the purposes of CAP but also for many medium-to-large scale photogrammetric applications. The aim is to provide the European Commission and the remote sensing user community with a general framework of the best approaches for quality checking of orthorectified remotely sensed imagery, and the expected best practice, required to achieve good results.

Since the last major revision (2003) the document was regularly updated in order to include state-of-the-art technologies. The major revision of the document was initiated last year in order to consolidate the information that was introduced to the document in the last five years. Following the internal discussion and the outcomes of the meeting with an expert panel it was decided to adopt as possible a process-based structure instead of a more sensor-based used before and also to keep the document as much generic as possible by focusing on the core aspects of the photogrammetric process. Additionally to any structural changes in the document new information was introduced mainly concerned with image resolution and radiometry, digital airborne sensors, data fusion, mosaicking and data compression.

The Guidelines of best practice is used as the base for our work on the definition of technical specifications for the orthoimagery. The scope is to establish a core set of measures to ensure sufficient image quality for the purposes of CAP and particularly for the Land Parcel Identification System (PLIS), and also to define the set of metadata necessary for data documentation and overall job tracking.

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